FINAL REPORT

DEVELOPMENT OF A CONTINUOUSLY OPERATING SOURCE OF VACUUM ULTRAVIOLET AND SOFT X-RADIATION

Contract NAS 5-3910

Prepared By

Space Sciences, Inc.
301 Bear Hill Road
Waltham, Massachusetts

For

Goddard Space Flight Center
Greenbelt, Maryland

SPACE SCIENCES | INCORPORATED

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ABSTRACT

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This final report describes the research and development of an intense vacuum ultraviolet and soft X-radiation source which provides line radiation at wavelengths less than 500 Angstroms. The method developed utilizes a vacuum arc where the arc is confined within a magnetic mirror field (Duo Plasmatron Type Source). With this source bright line spectra of Helium I and Helium II have been obtained.

This report contains a summary of pertinent activities during the development program. The design of the instrumentation which is to be delivered to NASA is reviewed.

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THE DEVELOPMENT OF A CONTINUOUSLY OPERATING SOURCE OF VACUUM ULTRAVIOLET AND SOFT X-RADIATION.

1. INTRODUCTION.

This final report describes the development of a continuously operating source of vacuum ultraviolet and soft X-radiation for use in the wavelength region between 10 and 1000 Angstroms. The objective of this research has been to develop a convenient laboratory sized source capable of providing a continuous high intensity point source of vacuum ultraviolet radiation. At the start of this project, it was realized that the most efficient source arrangement would utilize an electric arc restrained within a magnetic field. However, in order to use an arc, some means must be provided for increasing the energy of electrons in the arc to over 60 ev, so that vacuum ultraviolet radiation would be produced. Secondly, it is imperative that techniques be developed to limit the erosion of electrodes, and to control the type spectral lines which would be produced. During the first quarter of this development contract, it was discovered that a similar source to the one under consideration had been developed in the field of nuclear physics (ref. 1) and applied as a spectroscopic source (ref. 2).

This source has been referred to as a Duo Plasmatron Source. Consequently, during the first quarter, the development emphasis shifted towards establishing that this type source could be used for the production of radiation at wavelengths less than $500A^{o}$, and towards further modification of the source to operate as a reliable laboratory instrument. In the following sections the feasibility of an arc operating in a magnetic mirror to provide high intensity radiation in the short wave region and experimental details of the system are discussed.

In Section 2, background and feasibility are discussed. Here, the natural evolution of ideas which has culminated with the use of a Duo Plasmatron source are reviewed. As an adjunct to this, the conditions for producing vacuum ultraviolet radiation are analyzed as they apply to the Duo Plasmatron source. In Section 3, a complete description of the experimental system is given. Section 4, shows typical spectal results which have been obtained using Helium gas in the Duo Plasmatron type source. A discussion of results and experimental problems is also included here.

2. BACKGROUND AND FEASIBILITY

The Space Sciences' approach to the physical design for the arc source has evolved as a natural summation of two techniques which have been reported in the literature. These techniques include an energetic vacuum arc, and the compression of an electron beam induced discharge by means of a magnetic mirror. The merger of these two techniques is the Duo Plasmatron technique, and it is shown in the following sections that this technique will provide the solar spectroscopist with a strong continuously operating source of radiation spanning the soft x-ray region.

The energetic arc, studied extensively by Luce (Reference 3) and reviewed briefly in the next section, has shown remarkable efficiency in producing copious vacuum ultraviolet radiation. Measurements have indicated that as much as 50% of the input arc power appears as radiation below about 1200°A. The input power in this instance was about 30 kilowatts and the arc was 6 feet in length. Clearly, the arc in this form is unsuitable as a feasible and flexible laboratory source. However, the arc and its power requirements can be scaled down to values more reasonable for the application to a laboratory vacuum ultraviolet source. The energetic arc column employed by Luce was constrained by means of an axial magnetic field between widely separated electrodes.

By shaping the magnetic field so that it closes at the ends, the flow of current can be restricted, and power conserved. One such application has been reported by Alexeff (Reference 4). Alexeff has observed the radiation characteristics from a weak plasma generated in a mirror field by means of an energetic electron beam. This study demonstrates some of the techniques for effective plasma trapping in the mirror field. However, in Alexeff's work, the charge carrier density was not high, and consequently, the radiation rate was lower than that reported by Luce.

2.1 The Energetic Arc of Luce.

The energetic arcs which have been studied , range in arc column length from 6 inches to 6 feet. For arc currents of 250 amp, the arc voltage drop was 120 v for the 6-foot arc, and 55 v for the 12-inch arc. With the configuration employed the 12-inch arc was operated at currents down to 50 amp (i.e., at a power level of 2.5 kilowatts, approximately). The energy radiated by a 1-foot section of the 6-foot arc operating at a power level of 30 kilowatts (5KW/ft) was determined by a calorimetric technique. The results indicated between 2.5 and 3KW of radiant power suggesting a radiation efficiency of more than 50%. Moreover, most of this radiation was determined to lie in the vacuum ultraviolet spectrum below 1200 Å. Experiments show that the ion and electron temperatures are comparable numerically to the arc drop voltage, i.e. $k\,T_e \approx k\,T_i \approx 50$ to 100 electron volts. The ion-electron density in the arc plasma was determined to lie in the range of 10^{13} to $10^{14}\,cm^{-3}$.

In the energetic vacuum arc, a large current is passed between two electrodes in vacuum. By passing a large current through the system, the surface of the arc electrodes is volatalized. It is the molecules from the electrodes which ionize and migrate between electrodes constituting the current. This is a "bootstrap" effect where the flow of current is usually limited by an external circuit resistor. Obviously, the current flow must be great enough to supply the charge carriers by volatalization.

Although the current density must be high at the electrodes, the charge carriers will normally diffuse from the axis of the arc. In the Luce arc, a solenoidal field is used to restrict this radial migration. In the proposal of this contract, Document Number SSI-P-91A, it was shown that this magnetic restriction is beneficial in increasing the electron-ion density (n) in the arc column (Refs. 3-8). It was shown that in this arc $n_i \cong n_e \cong 10^{14}\,cm^{-3}$ and that the power radiated in the Bremsstrahlung continuum is proportional to n^2 according to the equation

$$P_1 = \frac{1.9 \times 10^{-21} z^3 n^2}{\lambda^2 (kT_e)^{1/2}} \exp\left(-\frac{1.24 \times 10^4}{\lambda kT_e}\right) \text{erg/cm}^3 \text{ sec A} \tag{1}$$

With $n \simeq 10^{14} cm^{-3}$, the total Bremsstrahlung yield is about 10^5 ergs/cm^3 sec. In addition there is a bright line spectrum where power radiated is described by the proportionality

$$P_2 = n_o \nu^3 g f \exp(-E/kT) \tag{2}$$

and it was estimated that individual spectrum lines may account for as much as 10^8 ergs/cm^3 sec.

These radiation levels are desirable for a useable laboratory source but the power requirements are not satisfactory for spectroscopic instrumentation. One way to limit the power in the arc is to shape the magnetic field so as to restrict the flow of current except very close to the tube axis. In the energetic vacuum arc the magnetic confinement is two dimensional (Figure 1). A method to conserve more power involves enhanced magnetic confinement as shown in the next section.

2.2 The Magnetic Mirror of Alexeff

In the technique of Alexeff, the electron ion density was only $10^{11} cm^{-3}$, the radiated power density 10^3 ergs/cm^3 sec and the input power approximately 2.5 kilowatts. Although the radiation levels are not as desirable as those used by Luce, the power requirements are obviously more applicable. Again, as shown

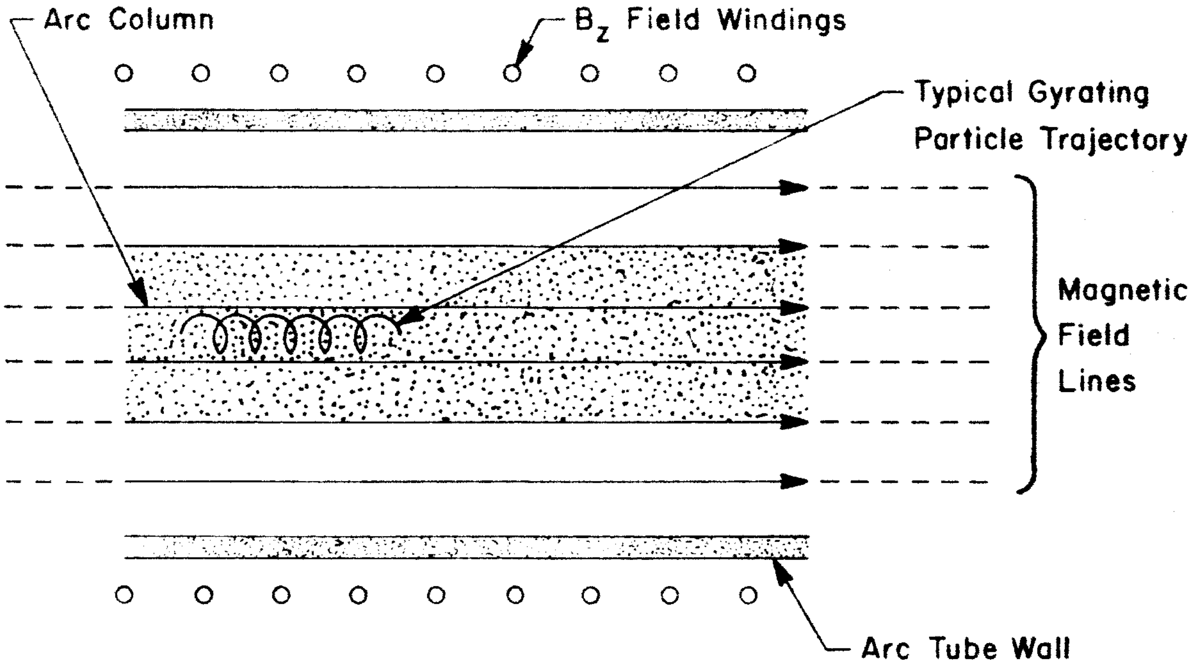

FIGURE I.

TYPICAL GEOMETRY FOR THE ENERGETIC ARC.

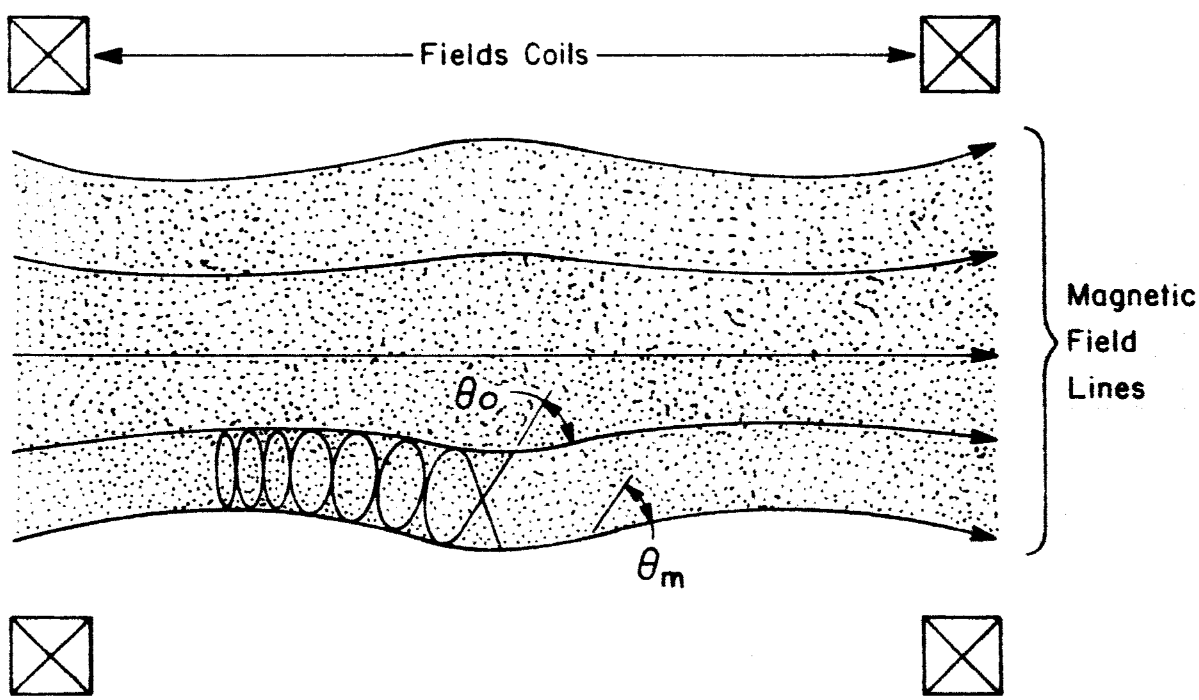

FIGURE 2.

CONTAINMENT GEOMETRY IN THE MAGNETIC MIRROR.

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in the proposal for this contract, the key to the lower power requirements is a three dimensional magnetic restriction (Figure 2). The reason for this power conservation follows from the fact that a gyrating particle is slowed in its progress into regions of increasing field (Ref. 5). The dominant loss mechanism for particles in a three dimensional magnetic field is due to Coulombic scattering of charged particles at the rate

$$R = n_i \cdot \frac{1}{t_c} \cdot V$$

where

$$t_c = \frac{11.4\, A^{1/2} T^{3/2}}{n_i\, z^4 \ln \Lambda}$$

and t_c is the collision time as given by Spitzer (Ref. 5). Typically $t_c \cong 10^{-5}$ seconds and $R \cong 10^{19}$ V particles/second where V is the containment volume. From this treatment, it can be shown that the rate loss of magnetically confined charges is significantly less than the loss of unrestrained charges as in the Luce arc.

Aside from illustrating the usefulness of magnetic constriction, the Alexeff system was not spectroscopically advantageous because of the low density and the high electron energy. The technique which combines the best characteristics of the above methods as applied to a vacuum ultraviolet source is embodied in the Duo Plasmatron technique described below.

2.3 The Duo Plasmatron of Von Ardenne

In the Von Ardenne Duo Plasmatron as reviewed by Moak (Ref. 9), the total power consumption is less than 500 watts. Of this, the arc consumes

150 watts, the magnetic field requires 250 watts, and the filament used to initiate the arc requires 70 watts. Typical arc voltage drops are 70 volts, and typical arc currents are 2 amps. In this mode of operation, the separation between electrodes is less than one inch. The energy radiated from this plasma has not been determined, however line spectra have been shown by Samson (Ref. 2) in the range between 1500 and 500 Å. The remainder of the spectral parameters still need to be determined.

In the Duo Plasmatron, ion densities as high as $10^{14} cm^{-3}$ have been reported, a value similar to that reported for the energetic arc in spite of the lower power consumption. In addition, the entire source assembly requires a volume of only 100 in^3.

Although the general characteristics of this source have been reviewed, very little description has been given regarding the operation of the Duo Plasmatron source. The original source was designed by Von Ardenne and named by him. The source was designed to deliver proton currents of the order of an ampere. Several of these sources have been built and it appears they operate well in accelerator applications.

There are two design concepts which are basic to a Duo Plasmatron source.

1. The basic discharge is a three-electrode arrangement. The electrode placed between the cathode and anode has a small aperture which restricts the arc.

2. To the basic discharge is added a magnetic mirror field in the small region of high ion density. As mentioned earlier, this mirror field acts to reflect the electrons so that escape is possible only very near the axis. The arc is thus caused to draw down to a very small conical

envelope coming to a point at the anode. It is at the point of the arc-tip where ion densities of 6×10^{14} ions/cm^3 occur.

This system is shown diagramatically in Figure 3. In this design, the electrodes serve simultaneously as magnetic pole pieces, eliminating the need for a relatively ineffective air cored solenoid. Here the magnetic field can be concentrated across two electrodes where the spacing and diameter is small, thereby increasing the system efficiency. In addition, the voltage of the middle electrode and the magnetic field can be altered, which changes the total energy across the arc.

2.4 Experimental Considerations

It has been pointed out that this source is capable of producing both a bright line spectra, and a continua due to bremsstrahlung radiation. It is interesting to note the conditions for producing each of these types of radiation in the Duo Plasmatron type source.

2.4.1 Bremsstrahlung Radiation

In Section 2.1, it was shown that when monoenergetic electrons lose energy by free-free interactions, the bremsstrahlung radiation is emitted. The total power radiated for a transparent plasma, expressed in terms of power per unit wavelength interval is

$$P_{\lambda} = \frac{1.90 \times 10^{-21} Z^3 n^2}{\lambda^2 (kT_e)^{1/2}} \exp\left(- \frac{1.24 \times 10^4}{\lambda \, kT_e}\right) \frac{\text{ergs}}{\text{cm}^3 \text{ sec A°}}$$

where Z is the effective atomic number, kT_e is the electron temperature in electron volts, and n is the electron density in electrons per cm^3 and where λ

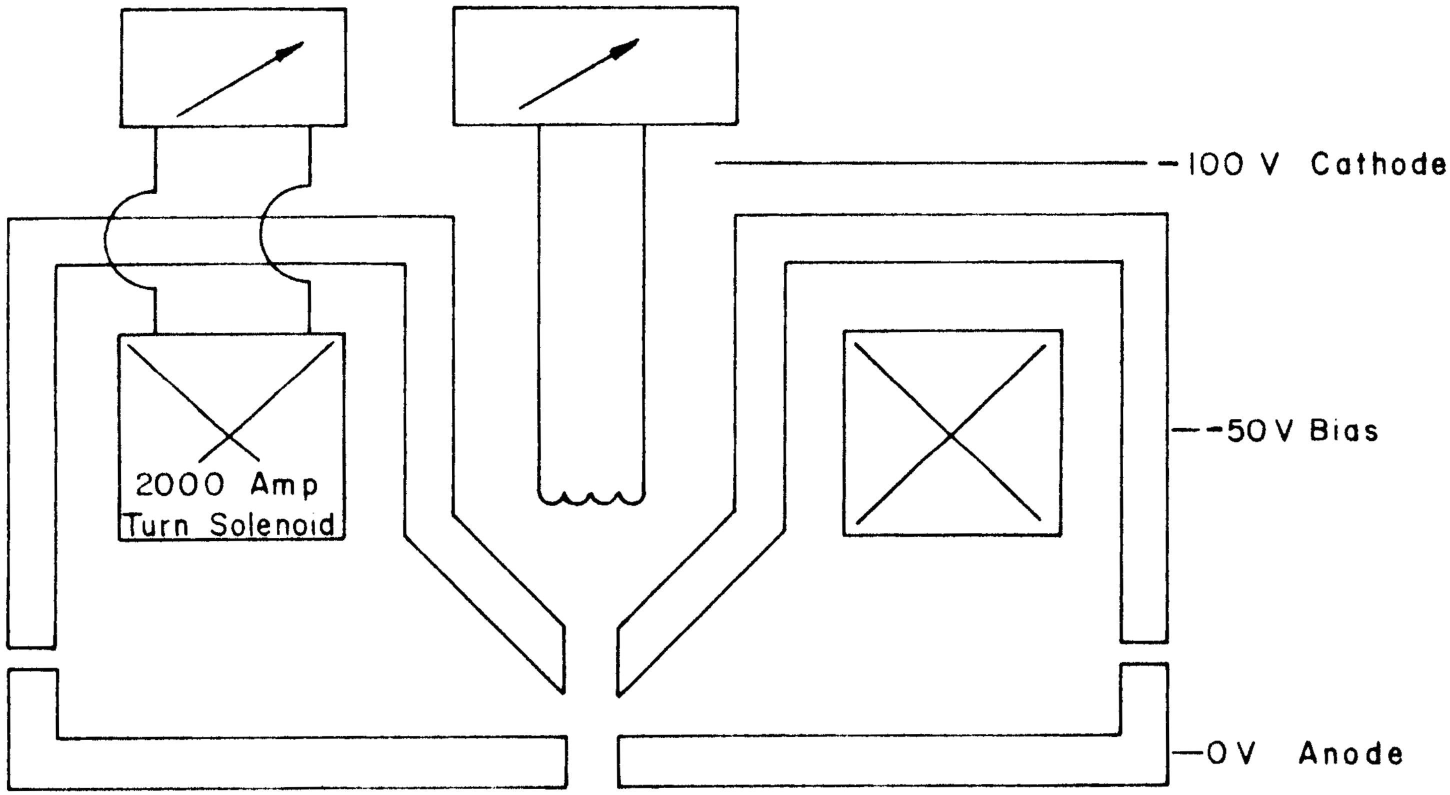

FIGURE 3.

SCHEMATIC OF DUO PLASMATRON ION SOURCE.

is in Angstroms. The spectrum has a maximum at

$$\lambda_m (kT_e) = 6.2 \times 10^3 \ (\mathring{A} \cdot ev) \tag{3}$$

Under ordinary source operating conditions, the filament is 150 volts negative with respect to the anode, while 30-40 volts may be measured between the grid and anode, (a distance of .025"). It has been reported [9] that at the point of the arc tip, ion densities of 6×10^{14} ions/ cm^3 occur. The bremsstrahlung radiation may be computed from equations (2) and (3). For this calculation, Z = 4(He), and $kT_e = 30$ ev. This equation gives the power per unit volume and the actual radiating volume has been estimated at .001 cm^3. The results are shown in Figure 4 from which it can be seen that bremsstrahlung radiation accounts for energy levels of about 1/2 erg sec^{-1} or 5×10^{-8} watts. This is probably less than our scattered light background, and has not been detected by us. In order to be able to detect bremsstrahlung radiation, an interesting possibility is to increase the Z number of the gas used. For instance, the use of Argon instead of Helium might increase the bremsstrahlung radiation yield 1000 times.

2.4.2 Line Radiation

In our Duo Plasmatron type source, a voltage difference of 30 volts exists across the arc gap, but a few electrons are accelerated from cathode potential (-150 volts) to the anode at ground potential. Those electrons which are accelerated without collision will have an energy up to 150 volts. Any lines with excitation potential less than 30 ev will be excited by the Duo Plasmatron source assuming that the energy is not great enough for complete ionization to exist. By adjusting the system pressure and the current transported by the arc, the case of total ionization can be avoided.

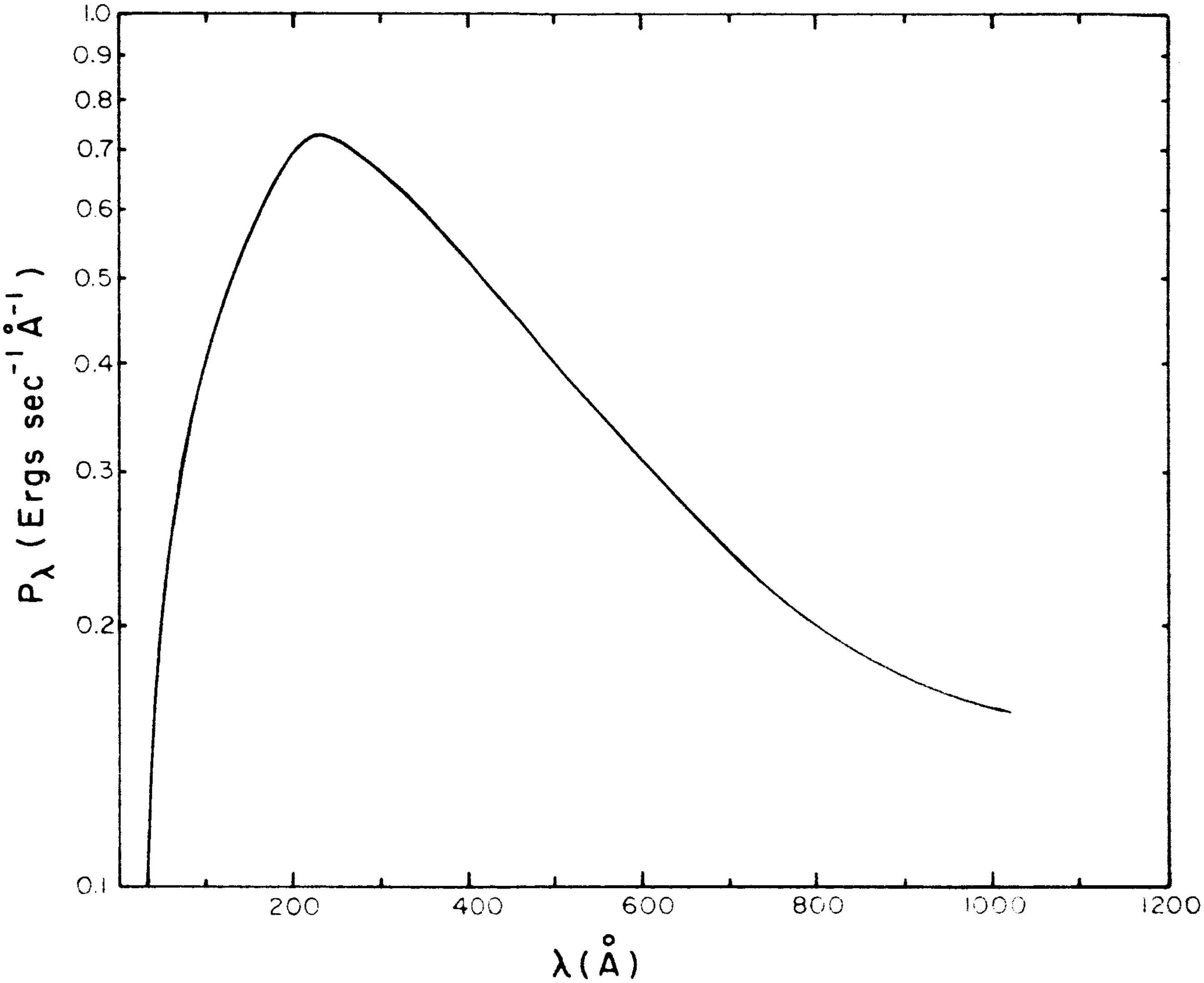

FIGURE 4.

BREMSSTRAHLUNG RADIATION FOR $kT_e = 30$ ev.

Unlike the case for bremsstrahlung radiation, the prediction of line intensities is extremely difficult. It is more feasible to experimentally evaluate line intensity. The theoretical line intensity is given by the proportionality

$$I \sim n_0 \gamma^3 gf \exp(-E/kT) \tag{4}$$

where n_0 is the number density of atoms in the ground state, g is the degeneracy of the upper energy state at the energy level E and f is the transition probability. Uncertainty in f-values and in n_0 impose severe limitations in accuracy in carrying out prediction calculations.

The gas which has been used for line investigation is Helium. In the vacuum ultravoilet region Helium I is excited at potentials less than 24.4 volts and Helium II is excited at potentials less than 53.8 volts.

From the source characteristics, it is apparent that He I lines should be produced by the arc. For He II to be produced by the arc, excitation must be produced by electrons which are emitted from the cathode, and which collide between the bias and anode electrodes. Both types of spectral lines have been detected.

3. THE EXPERIMENTAL APPARATUS

The apparatus which has been used for the experimental portion of the development program consists of four distinct parts, i. e., a vacuum system, a one half meter grazing incidence spectrometer, a Duo Plasmatron Source, and the source electronics. The important features of each of these components will be described in the following text.

3.1 The Vacuum System.

The vacuum system used is of conventional design, incorporating a valve system which permits protection of the hot diffusion pump oil. The system combines a 140 liter/minute Welch Duo Seal Pump and an NRC air cooled oil diffusion pump with a speed of 285 liters/second at 10^{-6}Torr. The system is capable of a base pressure of approximately 10^{-6}mm Hg.

The vacuum system is connected directly to a chamber which houses the grazing incidence spectrometer. The entrance slit of the grazing incidence spectrometer fits against a port in the vacuum chamber. The Duo Plasmatron source is mounted to the outside of this vacuum chamber and oriented so that the point source of radiation is along the optical axis of the vacuum ultraviolet spectrometer. This system is illustrated in Figure 5.

Gas is injected into the vacuum system through the Duo Plasmatron source. The gas which is injected is the gas whose spectra is to be detected, and it is this gas which supports the arc during operation.

3.2 The Grazing Incidence Spectrometer.

The Grazing Incidence Spectrometer is the same spectrometer which has been used under contract NAS 5-3365. It is a 1/2 meter grazing incidence type, with a grating density of 576 lines/mm and an 88° angle of incidence.

Two changes have been made from the standard spectrometer during the past development program. First, scattered light has been reduced.

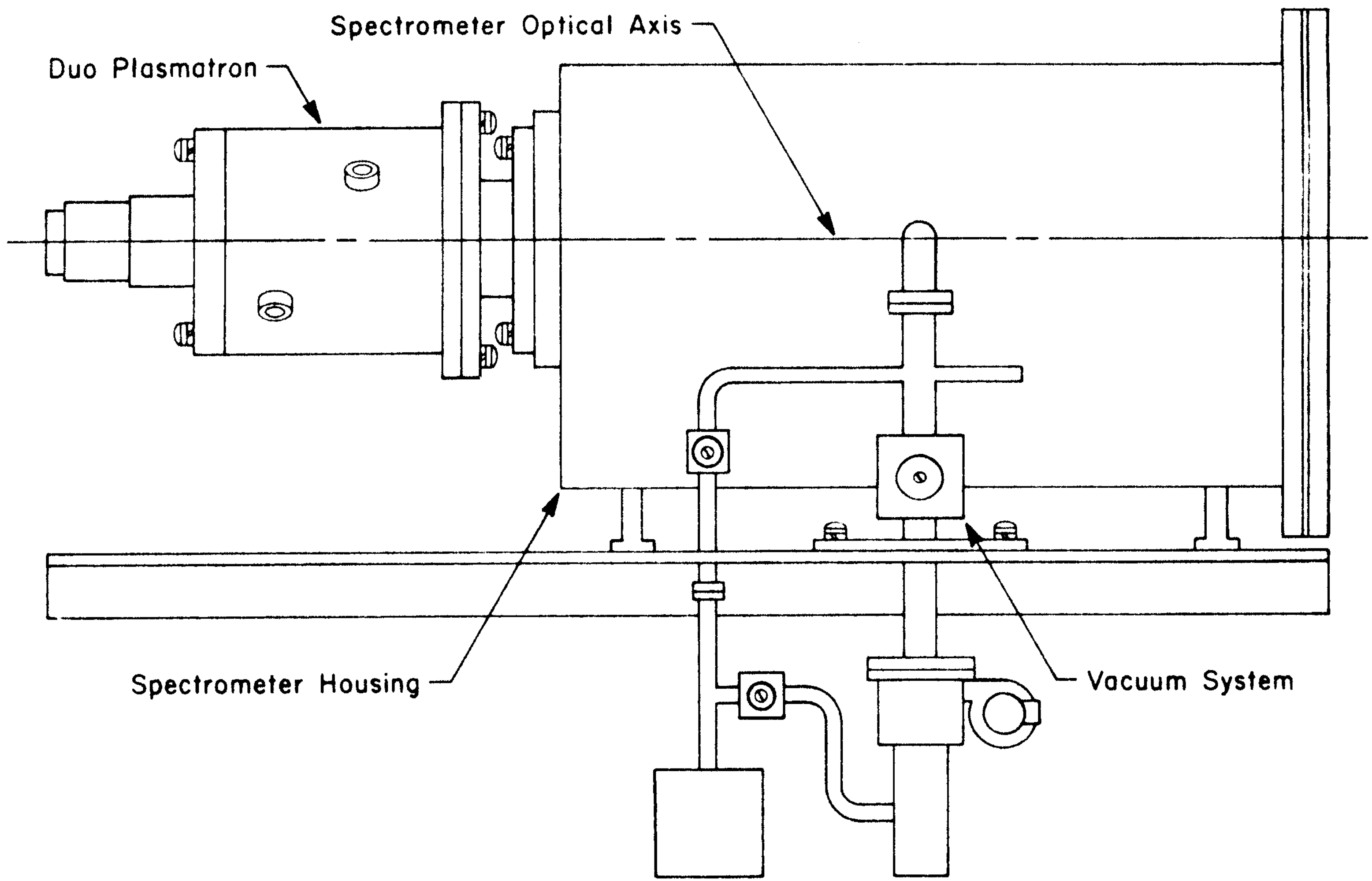

FIGURE 5.

THE EXPERIMENTAL SYSTEM.

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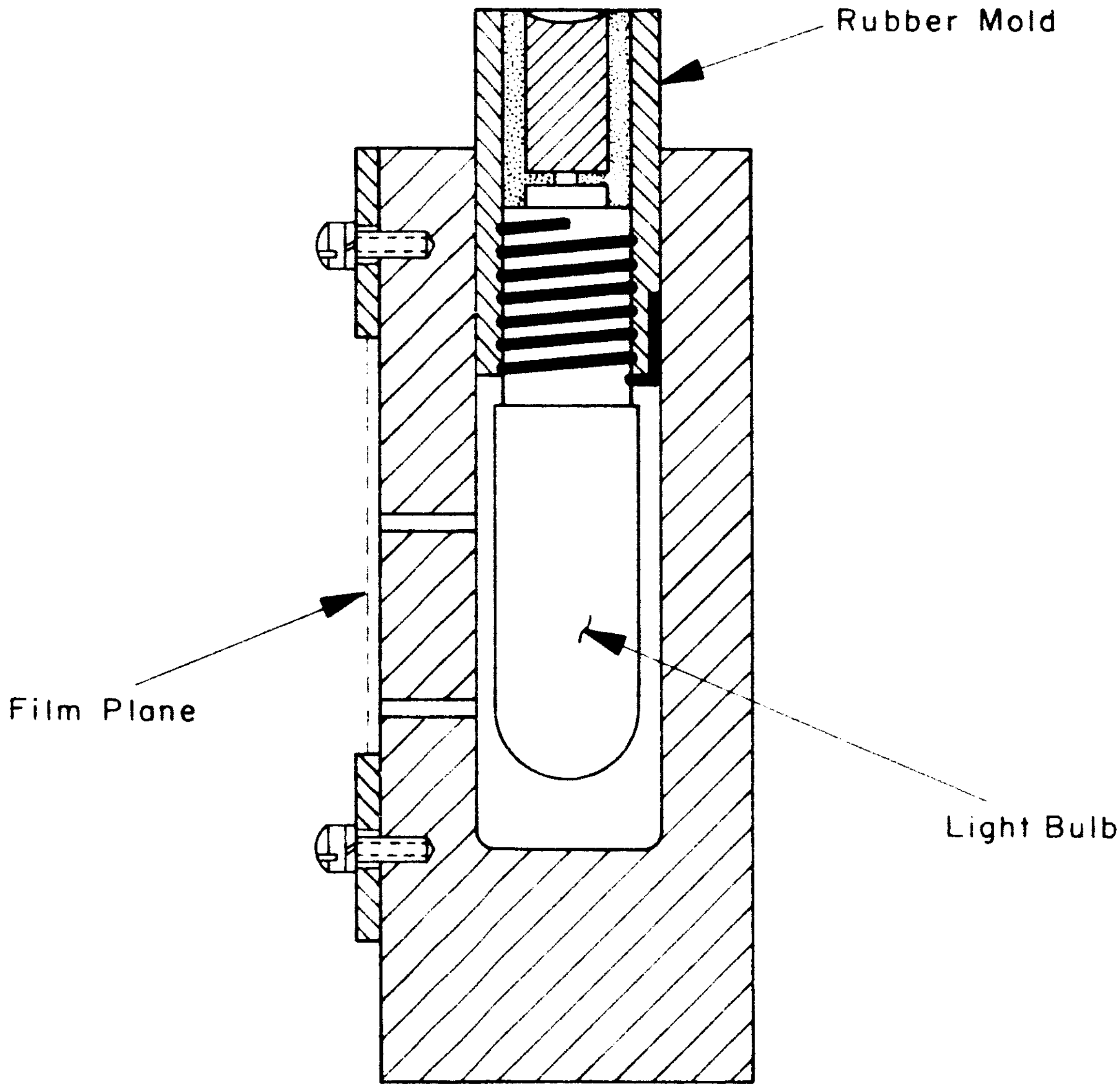

FIGURE 6.

THE FIDUCIAL MARKER SYSTEM.

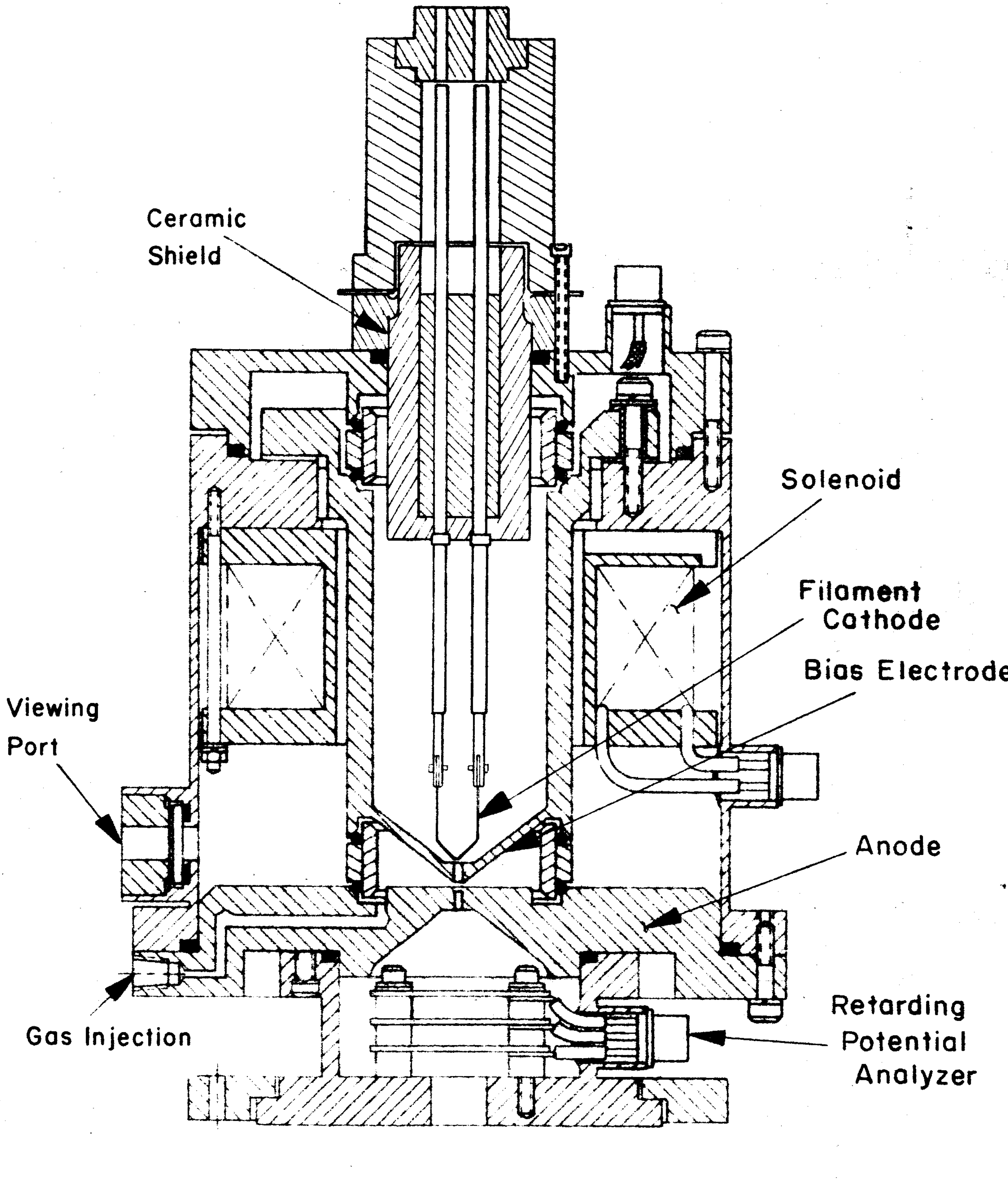

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FIGURE 7.
THE DUO PLASMATRON TYPE OPTICAL SOURCE.

All non-critical parts have been black anodized in order to prevent multiply reflected light from reaching the Kodak SWR Film. In addition, extra baffles have been added at the interface between the spectrometer and vacuum chamber. The second change which has been made comprises a reconstruction of the film holder. A new film holder was made because it was found that the first holder did not provide sufficient accuracy in adhering to the Rowland Circle. The new holder has a 50 centimeter radius of curvature, and conforms to the Rowland Circle with a deviation less than $\pm.005$ cm. In addition, a simple fiducial marker arrangement has been added in order to facilitate the superimposing of various spectra. This fiducial marker arrangement was found exceptionally useful since it also provided a constant exposure reference in order to check the film development process. The fiducial marker consists of two small holes (.013") in the film holder, perpendicular to the position of the film. A small light bulb is positioned behind the two holes and shielded so as not to scatter light onto other portions of the film. This system is demonstrated in figure 6. The light is activated in the darkroom after the spectrometer has been removed from the vacuum chamber. In this arrangement, one bulb electrode is connected to the spectrometer internally and the other is positioned on top of the fiducial marker assembly.

3.3 The Duo Plasmatron Source.

The Duo Plasmatron Source which has been developed during the development program is shown schematically in Figure 7. In order to assist the understanding of this source, reference to Figure 3 should be made.

The components which consitute the magnetic circuit are composed of soft iron. These components include the anode, the bias electrode, and that portion of the outer chamber which is between these two electrodes. The solenoid used for producing the magnetic field is supplied by 1000 turns of number 18 copper wire. The nose cone of the bias electrode is that portion of the magnetic circuit which saturates first. If one assumes that this saturation occurs at 12000 gauss, it may be shown that a solenoid current of 2 amperes is sufficient. Accounting for flux loss, it is expected that the magnetic field is about 7000 gauss between the bias and anode electrodes.

This magnetic field was measured in the first prototype Duo Plasmatron source. The total arrangement was similar to that shown in Figure 7. For the magnetic field measurements, a thin Hall probe was used as the field sensor. It was placed parallel with the anode electrode. The measurements obtained are shown in Figure 8.

Although the anode electrode is a flat plate, materials have been chosen for the plate so that there is a magnetic nose cone within the anode electrode. This arrangement should optimize the magnetic field to values slightly greater than those shown in Figure 8. A cross-sectional view of the anode plate is shown in Figure 9, where the ferrous materials are shaded. The copper insert is used to dissipate heat in the immediate vicinity of the anode spot.

The cathode structure must be capable of supplying sufficient electrons to sustain the arc. These electrodes are held in the vacuum system by two ceramic to metal seals which have been carefully insulated from the neighboring electrodes. Interelectrode breakdown has been a significant problem during the development of the Duo Plasmatron source structure. The actual filaments of Tungsten or Platinum are attached by screws to the metal electrodes. Several different types of filaments have been used in this structure. These include .015 inch Tungsten, .040 inch Tungsten and a Platinum -10% rhodium grid with .005 inch wires. With the latter, barium-strontium oxide emission solutions have been used.

Four O-ring vacuum seals are used in this source assembly. These vacuum seals are used to allow easy dissassembly of the source structure,

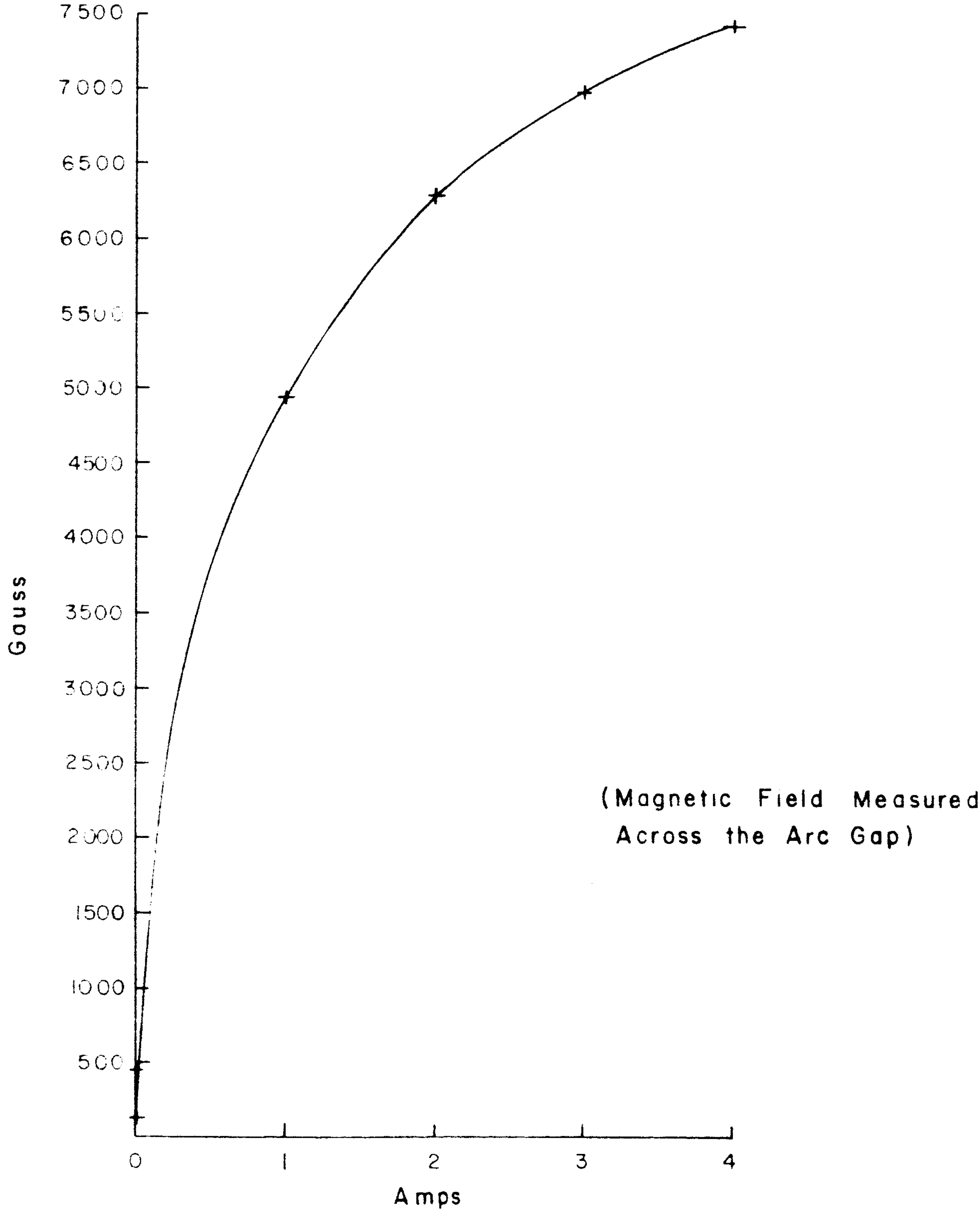

FIGURE 8.

MAGNETIC FIELD MEASUREMENT IN THE DUO PLASMATRON TYPE SOURCE.

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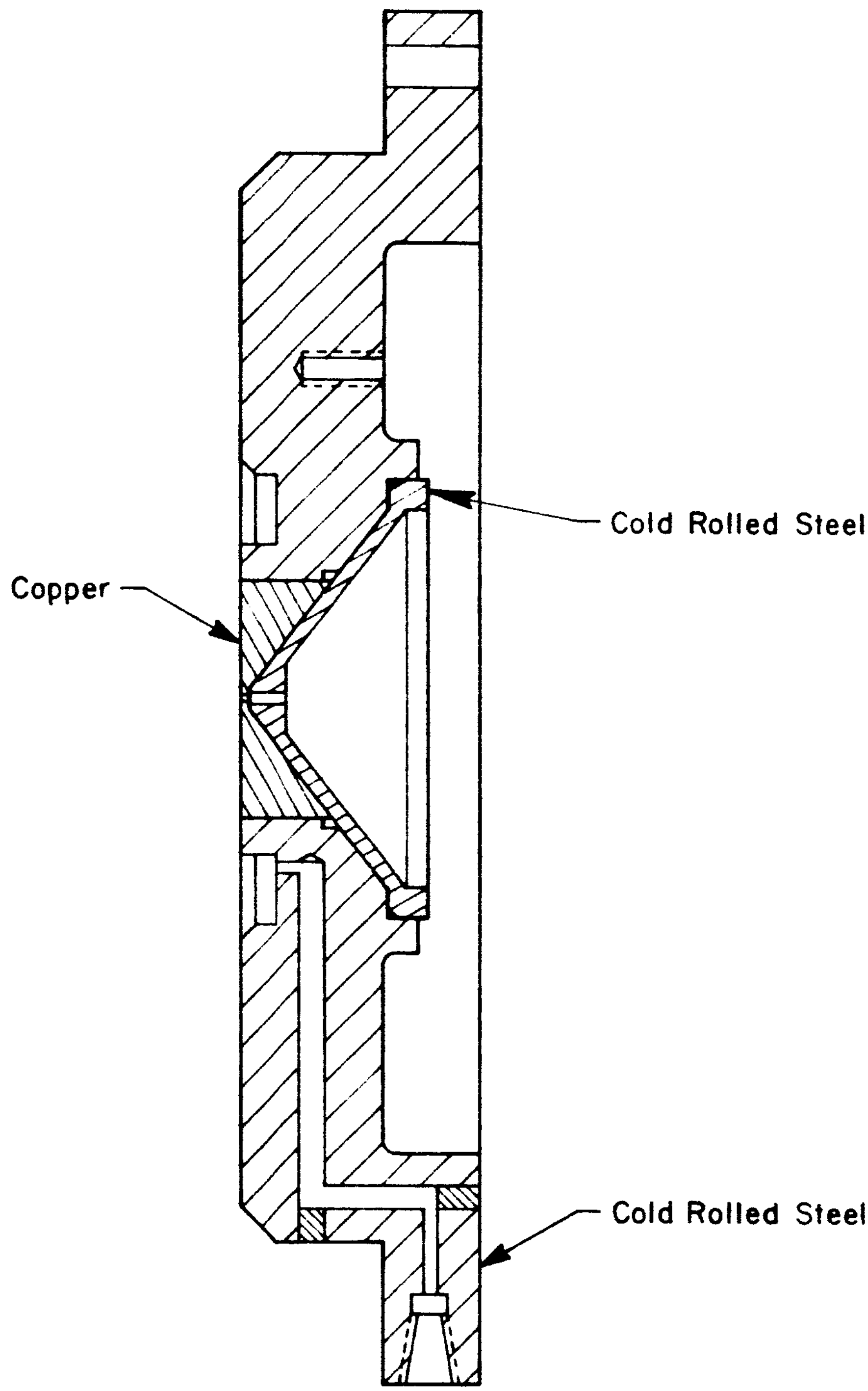

FIGURE 9.

SCHEMATIC OF ANODE ELECTRODE.

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should dissassembly be required. These seals are employed at the interfaces between the various electrodes. The O-rings are positioned between the outer surface of a glass tube and a polished metal groove. A plexiglas ring is used to force the O-ring against both the polished metal ring and the glass cylinder. Each plexiglas ring is used for two O-ring seals.

The glass to metal seals are cooled by circulating oil. This cooling is essential since 1 KW is dissipated in the source region.

At first Freon 113 was used as the coolant, but it was found difficult to use because of vapor formation once the circulating pump became warm. For this reason, insulating oil was selected as the final choice in coolants. Besides providing the required cooling facilities, this oil also acts as an insulation preventing breakdown outside the vacuum between the bias and anode electrodes. It is particularly useful where the interelectrode spacing is close.

3.4 <u>The Electronic Chassis</u>.

The electronic system is shown in the half tone picture of Figure 10. It consists of the electronic assemblies which are used to supply energy to the Duo Plasmatron source, and it houses the cooling system which cools the Duo Plasmatron source.

The cooling system comprises three major components. The fluid is pumped by a magnetically driven hot water pump. It then flows through a common refrigerator type heat exchanger. The same fan which cools the system electronics also dissipates heat from the heat exchanger. After the oil is pumped through the heat exchanger, it is carried out of the electronic system and into the Duo Plasmatron source by means of a flexible polyethylene tube. A second polyethylene tube returns the oil from the source to a one gallon storage tank located within the electronic chassis.

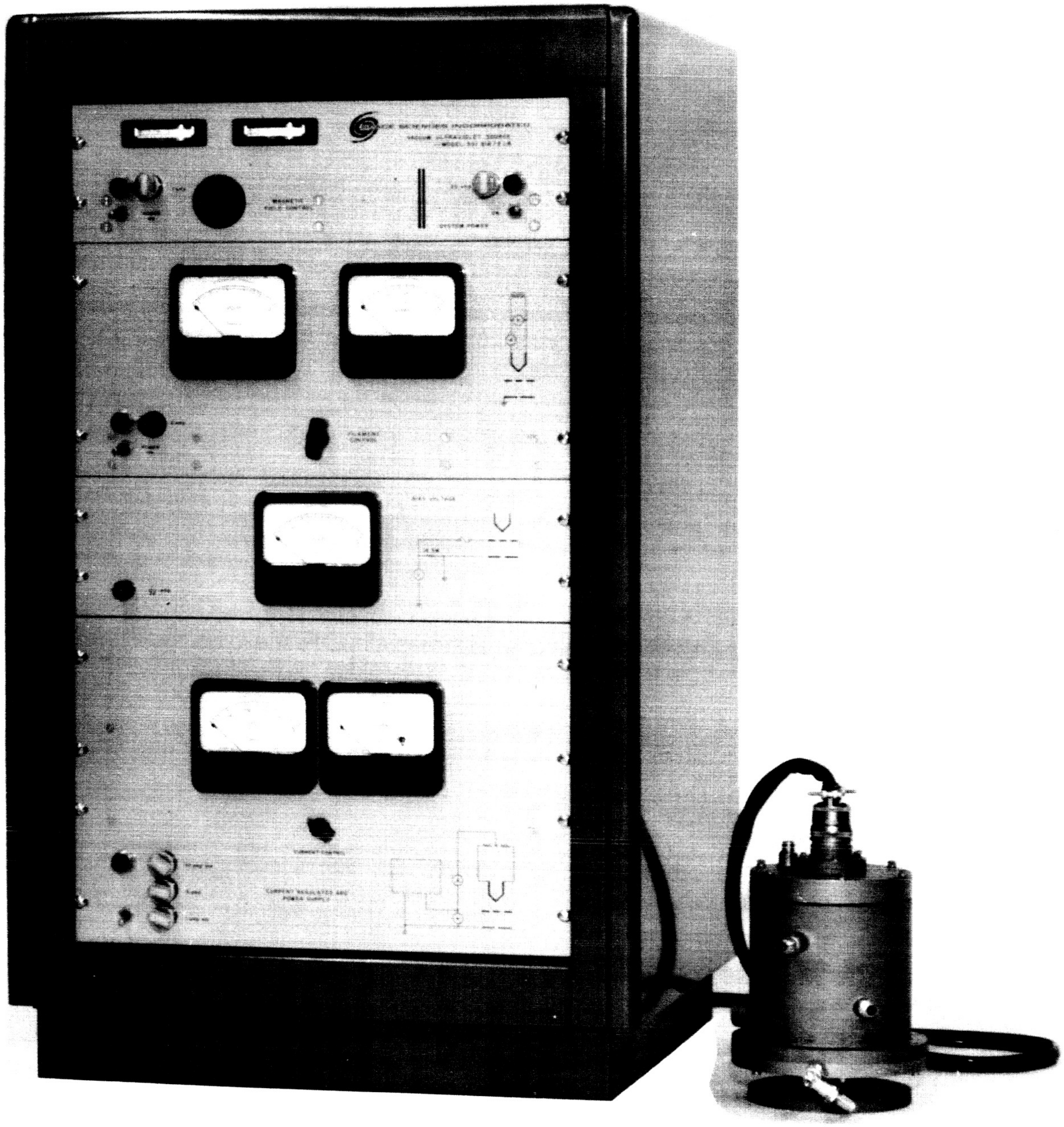

FIGURE 10.

THE DUO PLASMATRON SOURCE AND SYSTEM ELECTRONICS.

It was found necessary to place the heat exchanger after the circulating pump since the pump itself was found to heat up the circulating oil. By this re-positioning of the heat exchanger, the greatest ratio of output temperature to input temperature of the oil could be obtained.

The electronic circuits used incorporate seven panel meters in order to permit continual monitoring of the source behavior. The position of each of these meters is shown schematically in Figure 11. The interconnections between the filament supply, the bias supply and the current regulated arc power supply are also shown.

The circuit used for the current regulated arc power supply is shown in Figure 12. This circuit is the one shown by Moak et al (ref. 9) and has been only slightly modified for our use.

The filament supply is composed of a variac in series with a step down transformer capable of delivering 60 amperes at 3 volts. This is sufficient to heat .040 inch Tungsten to sufficiently high temperatures for electron emission to occur. The filament supply circuit is shown in Figure 13.

The magnet supply is a low voltage rectified and filtered D. C. circuit. which provides currents of 3 amperes and 30 volts. It is filtered for better than 1% ripple. Because the magnetic field coil is oil cooled, current regulation is not necessary in this supply. The magnet supply circuit is shown in Figure 14. The system power connections are also made in the magnet supply panel. The collant pump and fan are turned on automatically, when . the main power switch is activated. Power to each of the electronic sub-assemblies is then controlled individually.

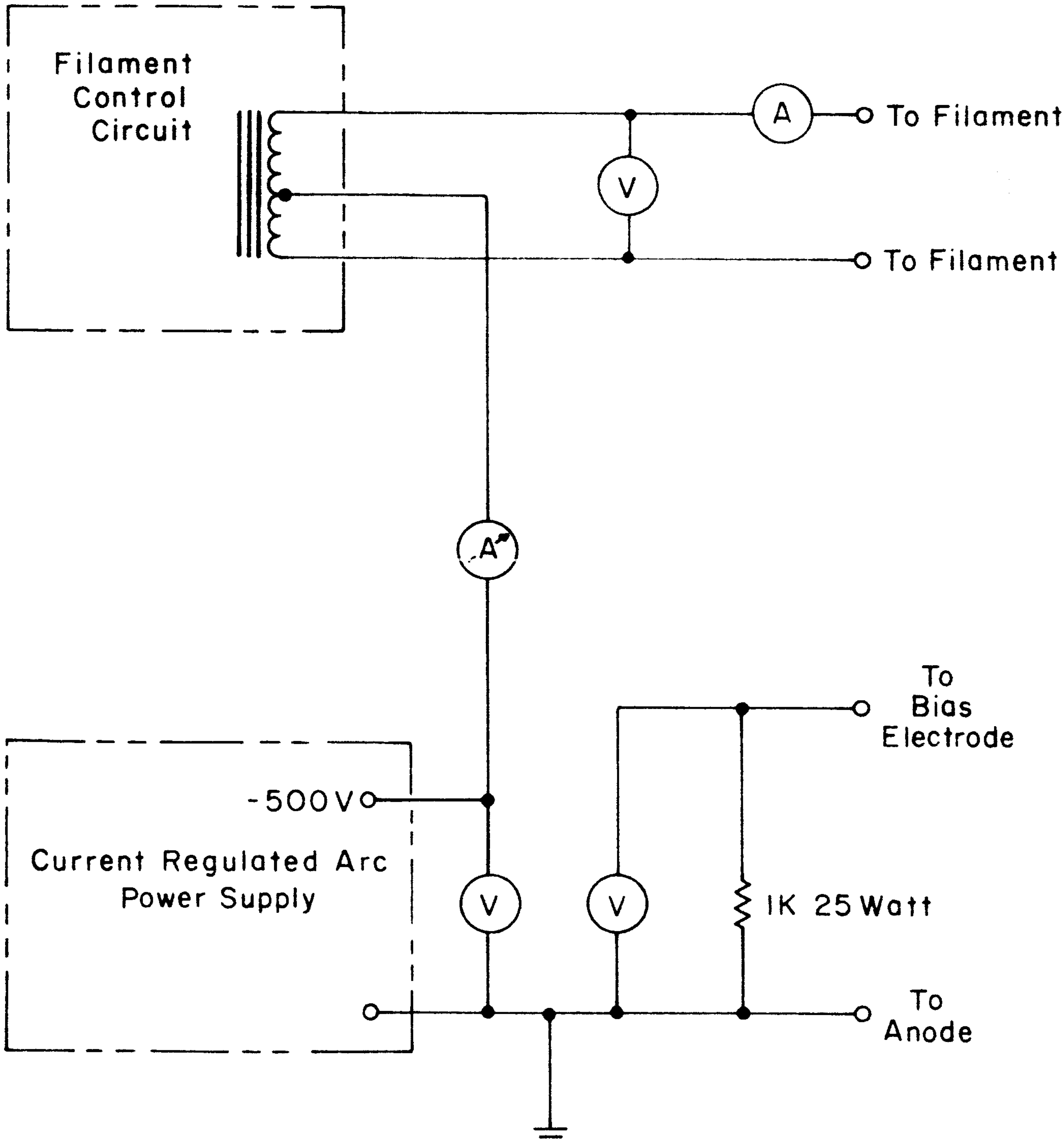

FIGURE 11.

GENERAL WIRING DIAGRAM.

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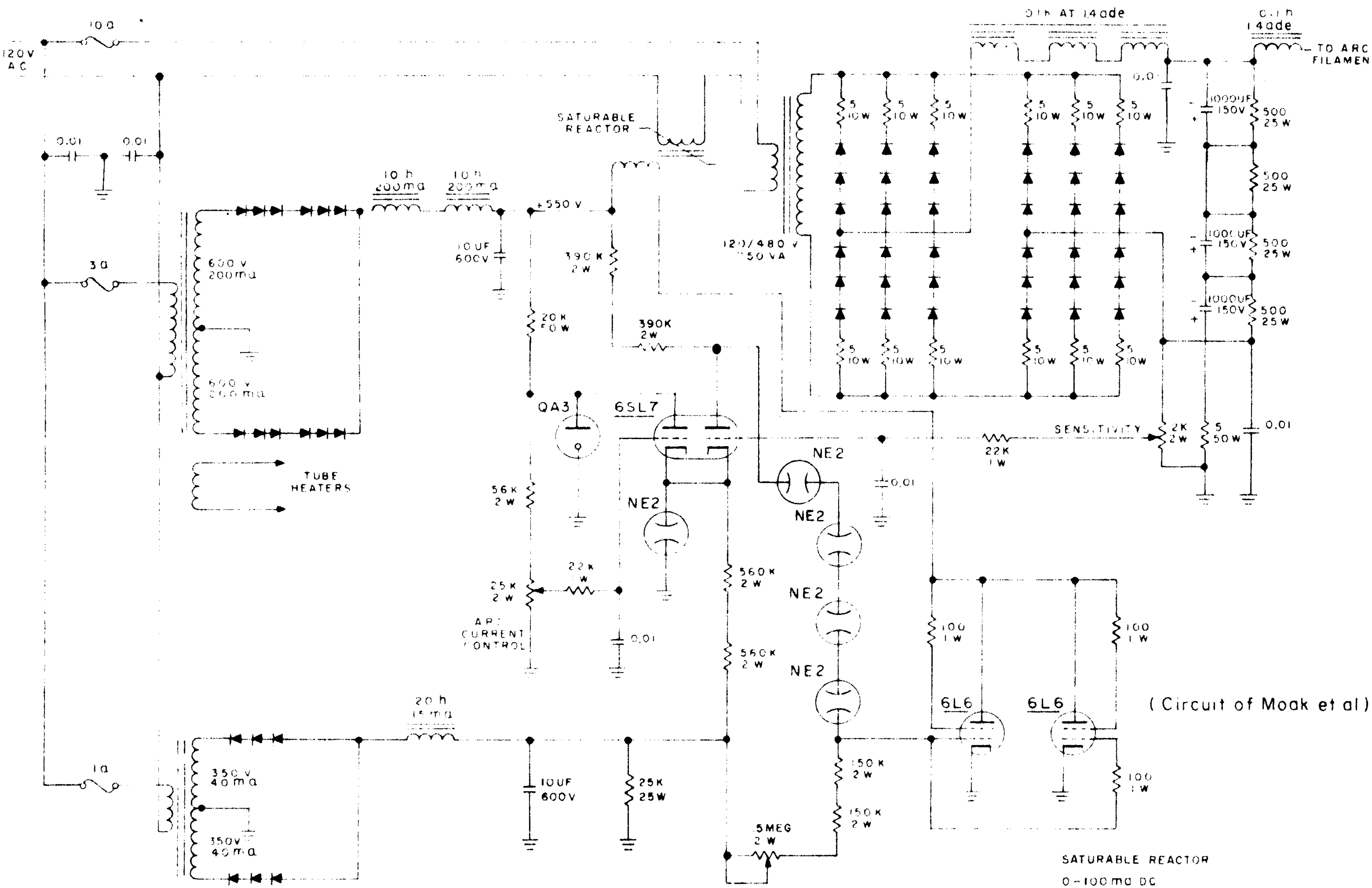

(Circuit of Moak et al)

SATURABLE REACTOR

0–100 ma DC

AC IMPEDANCE 2 TO 80 OHMS

ALL RECTIFIER STICKS 200 PIV

200 PIV 0.4 a

FIGURE 12.

CURRENT REGULATED ARC POWER SUPPLY.

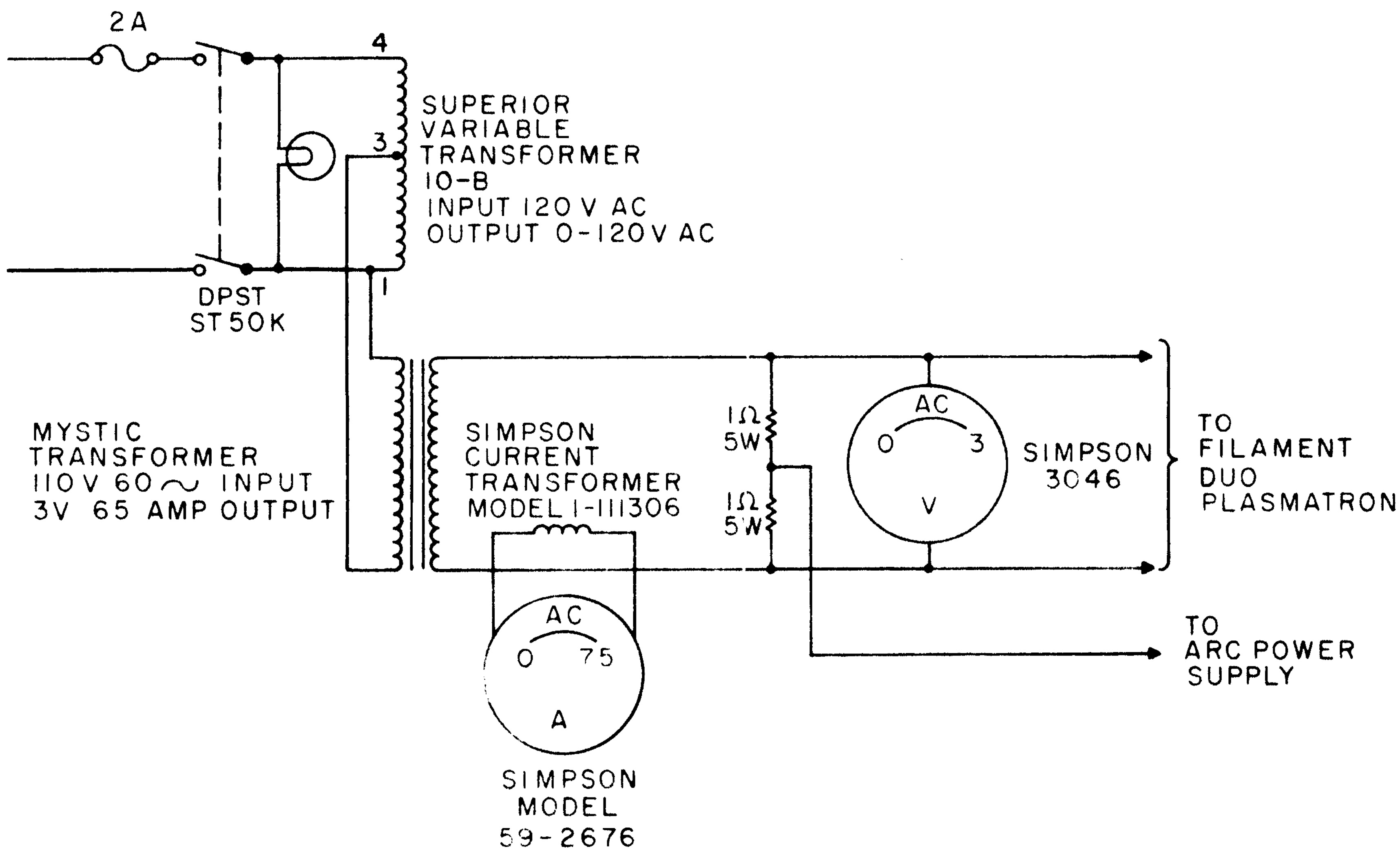

FIGURE 13.

THE FILAMENT SUPPLY CIRCUIT.

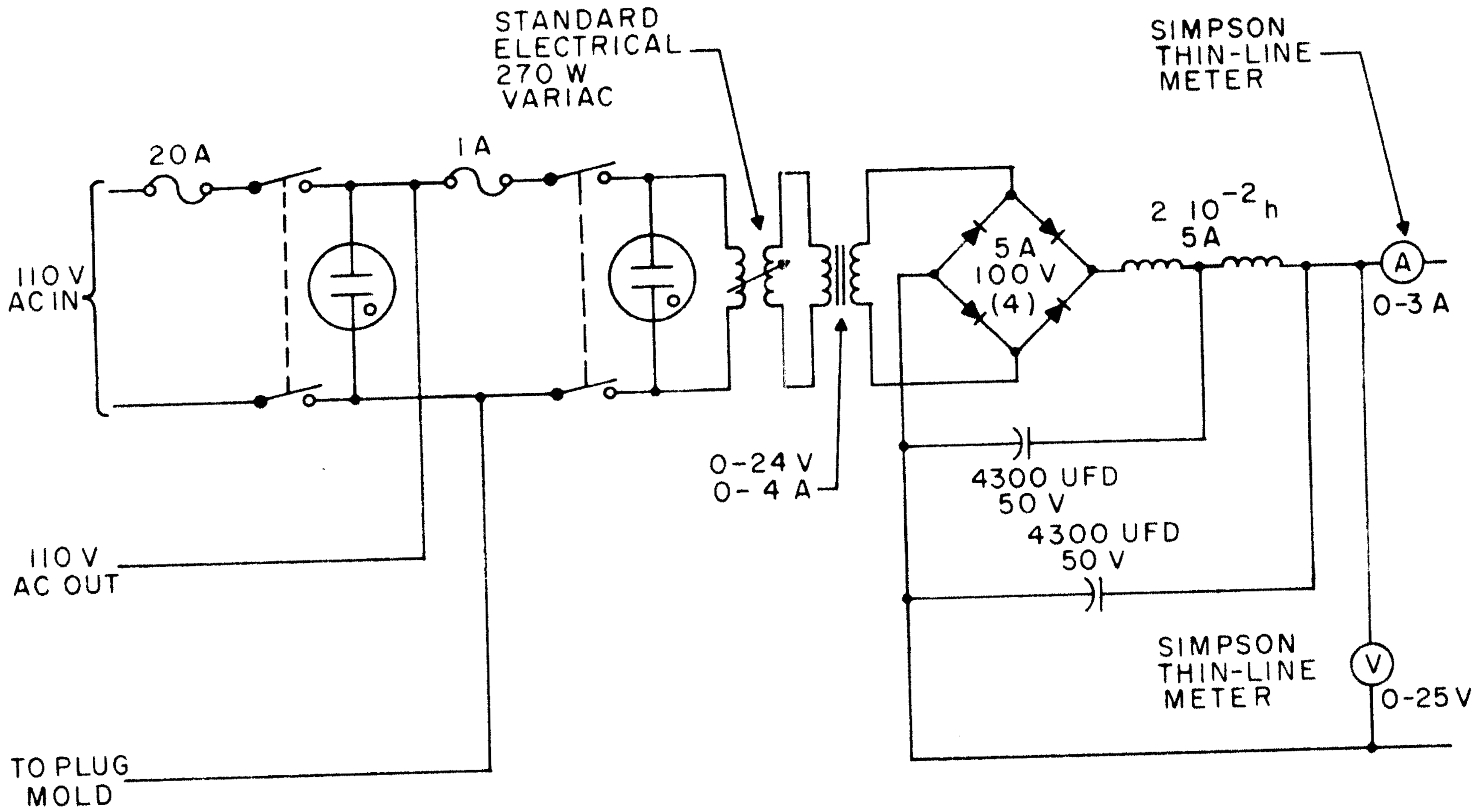

FIGURE 14.

THE MAGNET SUPPLY CIRCUIT.

4. RESULTS AND CONCLUSIONS

The major effort during the past year has been to develop a source which is capable of producing high intensity vacuum ultraviolet radiation in the wavelength region less than 500A°. The second goal has been to establish that the instrument behaves as a reliable laboratory equipment.

A typical vacuum ultraviolet spectra for Helium is shown in Figure 15. Most of the principle Helium II lines can be seen. Only one impurity line has been detected in this spectra, and it has been analyzed as a copper line. When this spectra was obtained, the only copper in the system was the support rod for the Tungsten filament which was seen to evaporate slightly under the maximum ion current (3 amperes).

It is suspected that this line is the copper 323.8 Å line. The line was identified from the spectrometer calibration chart which is shown in Figure 16. Distances are measured from the reference fiducial mark which also may be seen on the half tone reporduction of Figure 15.

The spectra was obtained after 15 minutes operation. The point source was located 5 cm from the entrance slit of the grazing incidence spectrometer. The slit width was .004" during this experiment, and the spectrometer grating was alligned with an accuracy of $\pm$.002". In other spectra the Helium II 304A° line could be detected after approximately 3 minutes of operation.

For the spectra shown, the filament was maintained at a potential of minus 100 volts with respect to the anode, and the bias electrode was maintained at minus 30 volts with respect to the anode. The arc current was between 2.0 and 3.0 amperes. The magnetic field was estimated at 7000 gauss, for utilizing 20 volts and 2.0 amperes. The filament current was 30 amperes through a 0.015" diameter Tungsten filament. Helium gas was injected into the

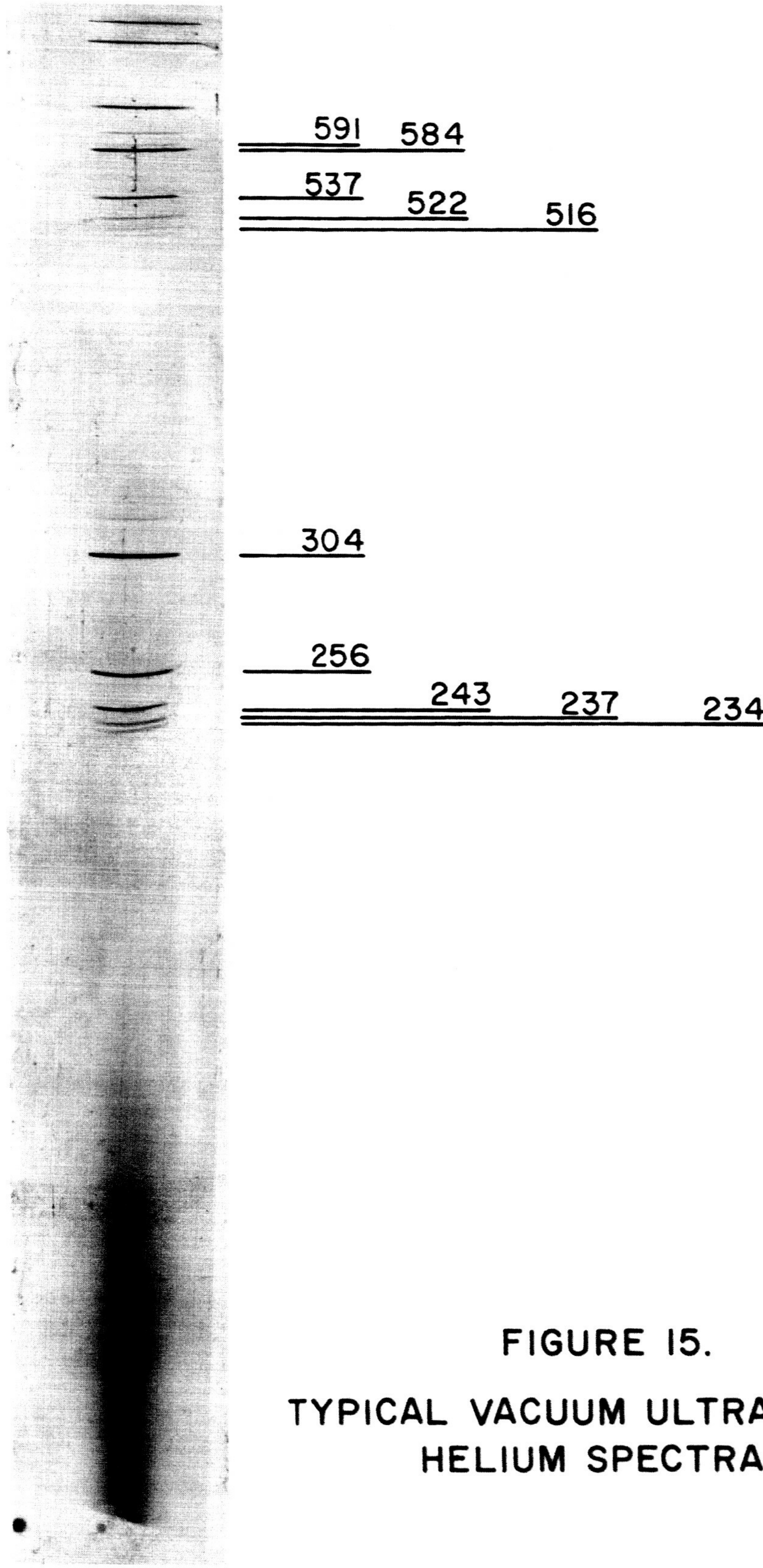

FIGURE 15.

TYPICAL VACUUM ULTRAVIOLET HELIUM SPECTRA.

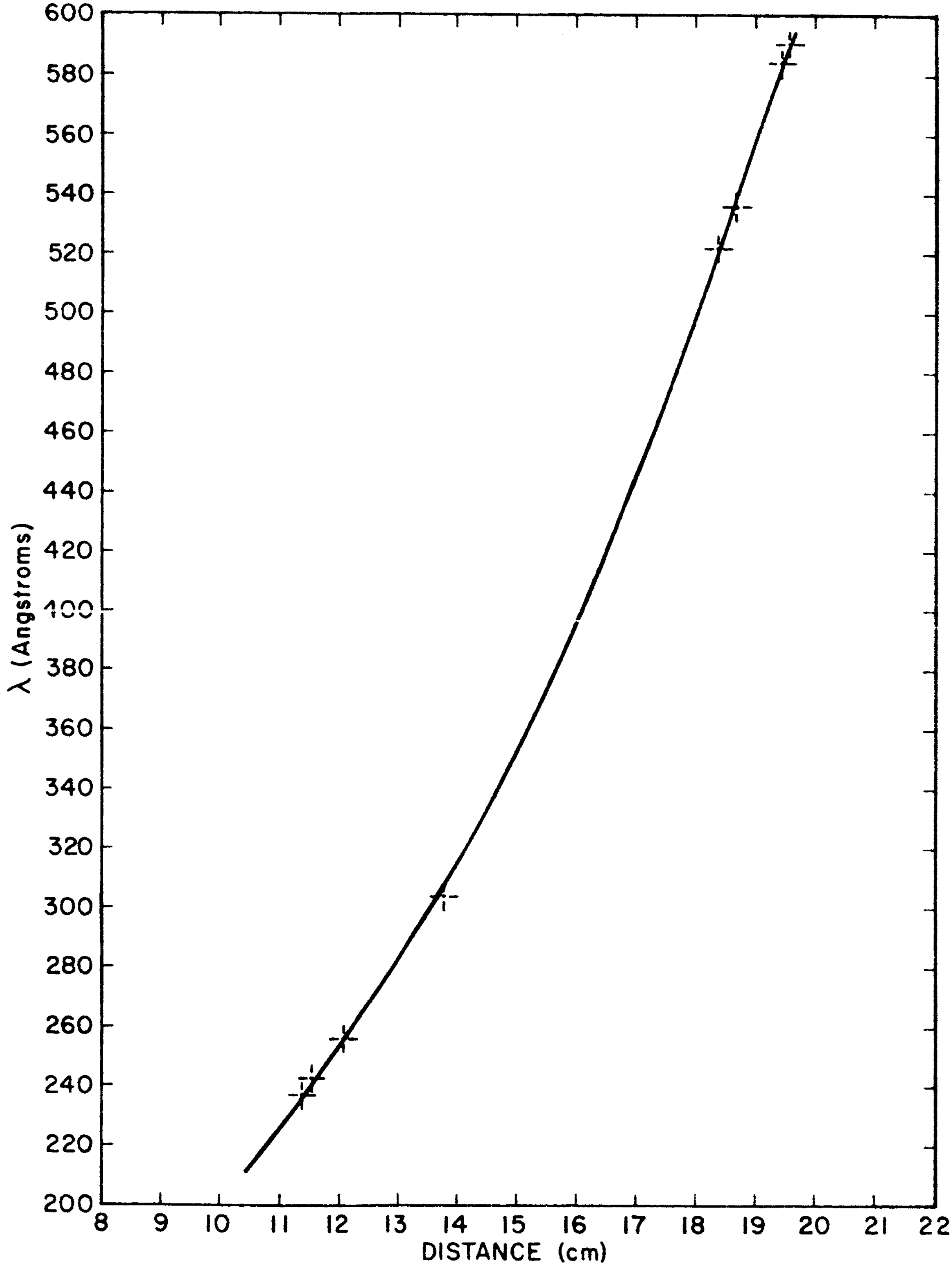

FIGURE 16.
SPECTROMETER CALIBRATION.

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system with a flow rate estimated at 10^{-2} torr liters/sec. and the base pressure of the system during operation was 1×10^{-4} Torr.

The film used was a Kodak SWR film. It was developed in Kodak D-19 developer diluted 1:1 from the standard solution with distilled water. The developer was maintained at 54°F during development. The film was then left in a standard fixer solution, Mr. Fixol, for five minutes. Before drying, the negative was rinsed for 30 seconds in a standard solution of Kodak photoflush.

The print was retouched slightly to remove the darkening of the film which was caused by scattered incident light. The relative intensity of the lines remains unchanged.

Problems with the operation of the source demanded a disproportionate amount of development time and has prevented other spectra from being obtained. These problems included the failure of Freon 113 to provide adequate cooling, and internal breakdowns between the filament and ground at points close to where the filament electrodes entered the system. Also, an examination of the conditions for maximum filament lifetime was required.

The breakdown problem was finally rectified by changing to the electrode system shown in Figure 7. The earlier structure is shown in the Third quarterly report of this project (Figure 2). The longest filament (4 hours) were found using the platinum mesh filament purchase from Englehard Industries which was dipped into a standard barium-strontium emission solution which was obtained from Raytheon Co. It was found that the filament limitation was the sputtering rate of the solution from the platinum grid. With the coated platinum filament there was no control of the cathode potential. Because of the efficient electron emission it remained at 70 volts during operation.

With Tungsten filaments, the cathode fall potential could be continuously varied by adjusting the filament temperature. It is expected that this is important since this cathode fall potential difference determines the energy of the electrons which interact in the arc region. With the coated filament, no filament heat was required and consequently the cathode voltage was at a minimum value of approximately 70 volts. If these cathode fall electrons are the ones which are essential for causing the high energy spectra, the behavior of the source is seriously limited with the coated filaments.

The source is now operating satisfactorily and several experiments of technical interest remain to be performed. The exact requirements for good spectral behavior have not yet been established. It is expected that the high energy spectra are obtained from the high energy electrons that originate from the filament. The optimum value has not been determined; once this is determined the modus operandi can be deduced. Other pure gases like Nitrogen and Hydrogen have not been used with the source. These gases have many excitation lines in the wavelength range less than $500A^{o}$. In addition, gases consisting of metal compounds like iron carbonyl (Reference 10) can be added to this source in order to duplicate portions of the solar spectra. Because the spectra produced is determined almost completely by the gas injected into the Duo Plasmatron source, it is expected that the results will be of high technical value. In addition, the source operates continuously, and from this beneficial measurements may be made on both detectors and filters which are effective in this wavelength range.

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